National Park Service
U.S. Department of the Interior

Greater Yellowstone Network

Watershed Classification Project
GREATER YELLOWSTONE NETWORK

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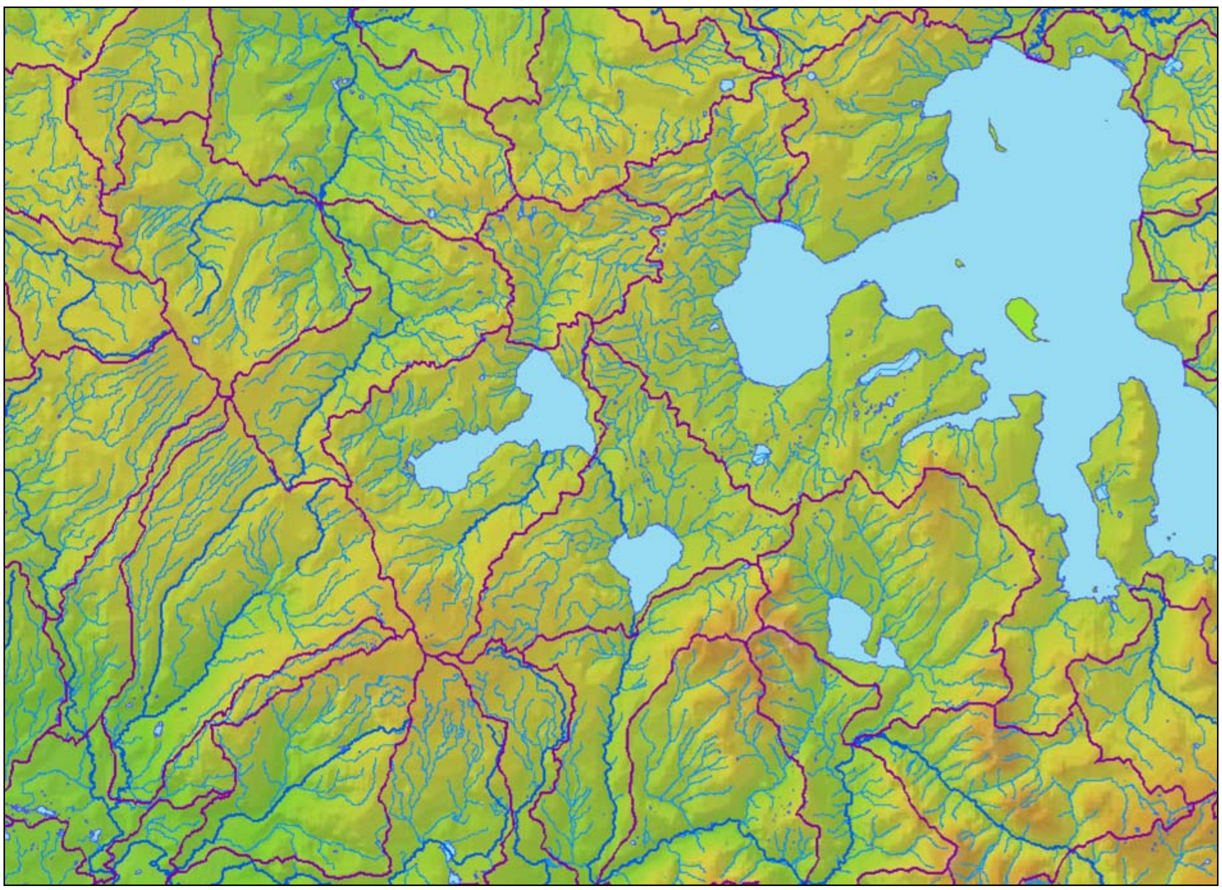

The level 6 HUC watersheds in Yellowstone National Park, in the south-central portion of the park.

APRIL, 2004

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INTRODUCTION

As part of the Vital Signs Monitoring Program, Outstanding Natural Resource Waters (ONRWs) are given a high priority for long-term monitoring. Therefore, the Greater Yellowstone Network (GRYN) must develop a sampling plan for its ONRWs that ensures adequate monitoring of these resources. Due to the large number of aquatic resources in the GRYN and the various scales at which the problem can be analyzed; the number of sites chosen for sampling can grow exponentially as the problem is addressed. To make this process manageable, a classification scheme for grouping similar watersheds, based on physical characteristics, was developed for Big Horn Canyon Recreation Area (BICA), Grand Teton National Park (GRTE) and Yellowstone National Park (YELL).

The choice of scale is critical in water modeling/monitoring because scale affects the level of detail used in the analysis. Too large of a scale results in a loss of resolution and important differences in the data; while too small of a scale contains more information than is necessary and the process becomes overwhelmed by too much detail. We chose the 6th level Hydrologic Unit Code (HUC) watersheds because they are a good balance between enough detail to differentiate units, but not so many units that we defeat the purpose of the classification in the first place. At this scale, the 3,380,300 acre study area is divided into 122 level 6 HUC watersheds. Choosing which watersheds to include in the study was a compromise between including all areas that flow into or out of the three parks and keeping the project small enough to manage. Every watershed fully contained within a park unit and every watershed that drained directly into a park unit was included. For the watersheds that drained out of a park and were only partially in the park, we included the watersheds when more than 50% of the watershed fell within a park unit.

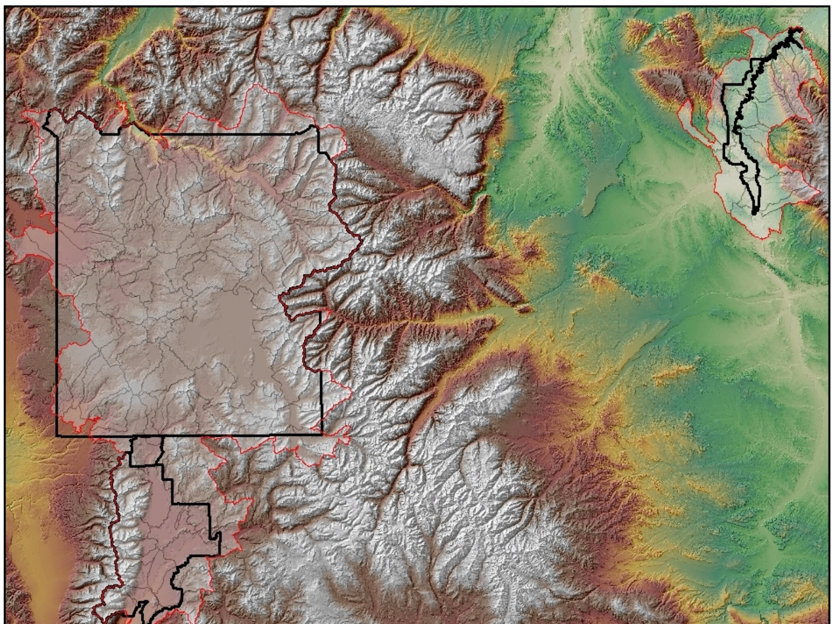


Figure 1. Location of the three parks and the study area.

Using geographic information systems (GIS), data layers representing environmental characteristics with known impacts on water quality (land cover/land use patterns, thermal areas, geology/soils, precipitation, and topography) were created to cover the study area. Multivariate statistical techniques were used to examine the differences among the watersheds. Based on the results from the analyses, the watersheds were divided into groups with similar physical characteristics. Throughout the process, aquatic specialists and/or hydrologists were consulted for input and insight into water quality impacts and stressors. The surface water classification scheme developed in this proposal will ultimately assist the network in fine-tuning its overall sampling/monitoring design by enabling the aggregation of HUCs to implement a stratified sample for water monitoring.

DATA LAYERS – METHODS & RESULTS

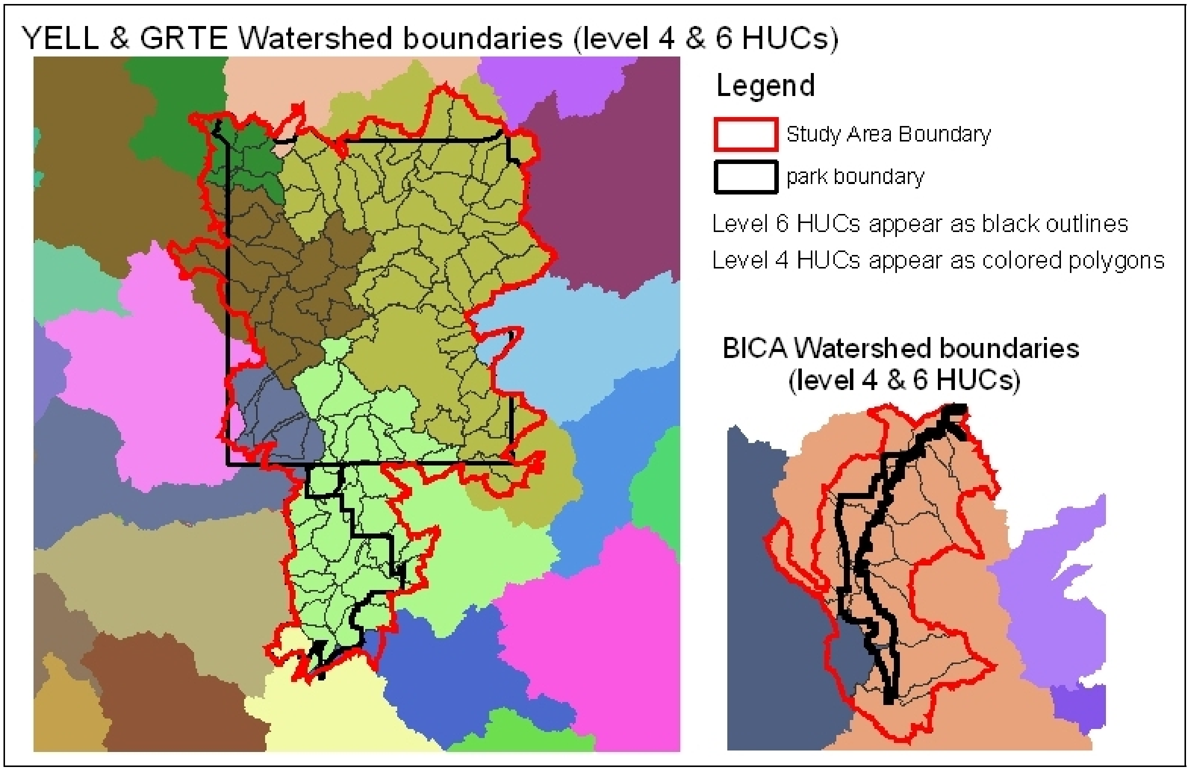
We identified, assessed, and collected GIS data layers for each park. These data included watershed boundaries (level 6 HUCs), surface water (lakes), precipitation, land cover, topography (slope, aspect, elevation), thermal areas, and geology/soils. These layers were edge-matched to cover the study areas and reclassified to reduce the number of categories and emphasize the factors that affect water quality. This reclassifying was based on what has been used successfully by other researchers (Sueker et al, 2001; Norris and Hawkins, 2000; Clow and Sueker, 2000; Srinivasan et al, 1998), and on the quality and scale of the available data. For example, using DEMs to calculate watershed area, average elevation, and fraction of basin area with slopes greater than or equal to 30 degrees was straightforward and the results are compatible across political boundaries. The source geologic data on the other hand varied greatly from one place to another and it was much more difficult to reclassify the existing attributes into categories that meant the same thing across boundaries and between edge-matches. After the layers were edge-matched and reclassified we calculated the percent of the total area that each category (GIS class) occupied in each watershed. These are the data that were used in the cluster analysis described in the section **ANALYSIS METHODS & RESULTS**.

WATERSHED BOUNDARIES:

A Greater Yellowstone Area (GYA) coverage of watershed boundaries was created by piecing together level 6 HUC coverages from Montana, Idaho, and Wyoming. This coverage was then clipped to the two study areas and formed the basis of the entire study. The total number of watersheds in the study is 122 (two watersheds are included with both YELL and GRTE). The watersheds range in sizes from approximately 10,000 to 50,000 acres. The map below shows the level 6 HUC watersheds included in the study and illustrates their relationship to the much larger, level 4 HUC watersheds in the area.

Park	Number of watersheds	Min size (ac)	Max size (ac)	Avg size (ac)
BICA	16	9,800	48,400	25,700
GRTE	21	15,400	40,600	24,300
YELL	87	10,400	47,850 (*210,400)	26,700 (*28,800)

* One watershed, the one surrounding Yellowstone Lake, is much larger than all the others. The maximum and average were calculated with this watershed and without it.



Data concerns:

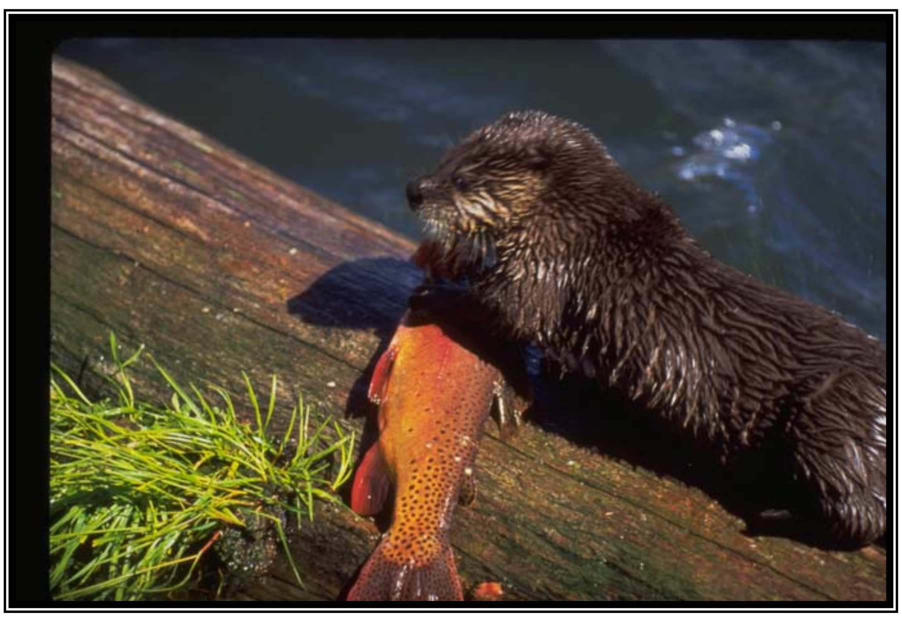
- * The watershed surrounding Yellowstone Lake (HUC# 100700010401) is much larger (210,400 acres) than the others in the study area and should be divided into at least 3 new watersheds.
- We would have liked to classify the watersheds by the order of the largest stream, but didn't receive the new NHD (National Hydrologic Dataset) in time. Watersheds that contain the source area of their largest stream are inherently different from watersheds where a large river enters and exits the watershed. Watersheds draining into large lakes function differently than other types as well.
- The quality of watershed delineation in the Idaho coverage was lower than in the other two states. The states are working on an agreed upon, GYA-wide, edge-matched coverage that will eventually replace this one.

Source Data for Watershed Boundary layers (Project DVD: Data/HUCs/Original_Data)

GYA_HUC_6 (GYAHUC6GRID)	"GYA"-wide 6th level HUC layer developed from individual layers from Idaho, Montana, and Wyoming (listed below). The boundary is based on NHD watershed boundaries that cover YELL, GRTE and BICA.
ID_6TH_HUCS (HUC_6)	Idaho 6th level HUC data downloaded from 'Idaho Water Clearinghouse'; http://inside.uidaho.edu/geodata/geo.htm
ID_6HUC_GYA	Idaho HUC data clipped to GYA boundary to be used in watershed classification project
gya_huc6.shp	Montana 6th level HUC data provided by the Interagency Spatial Analysis Center, Gallatin National Forest, Bozeman, Montana
wy_hu12.shp	Wyoming 6th level HUC data downloaded from WyGISC; http://www.wygisc.uwyo.edu/clearinghouse
wy_huc12_gya.shp	Same as 'wy_huc12.shp' but was clipped to the GYA using the hydrology boundary obtained from Sue O'Ney

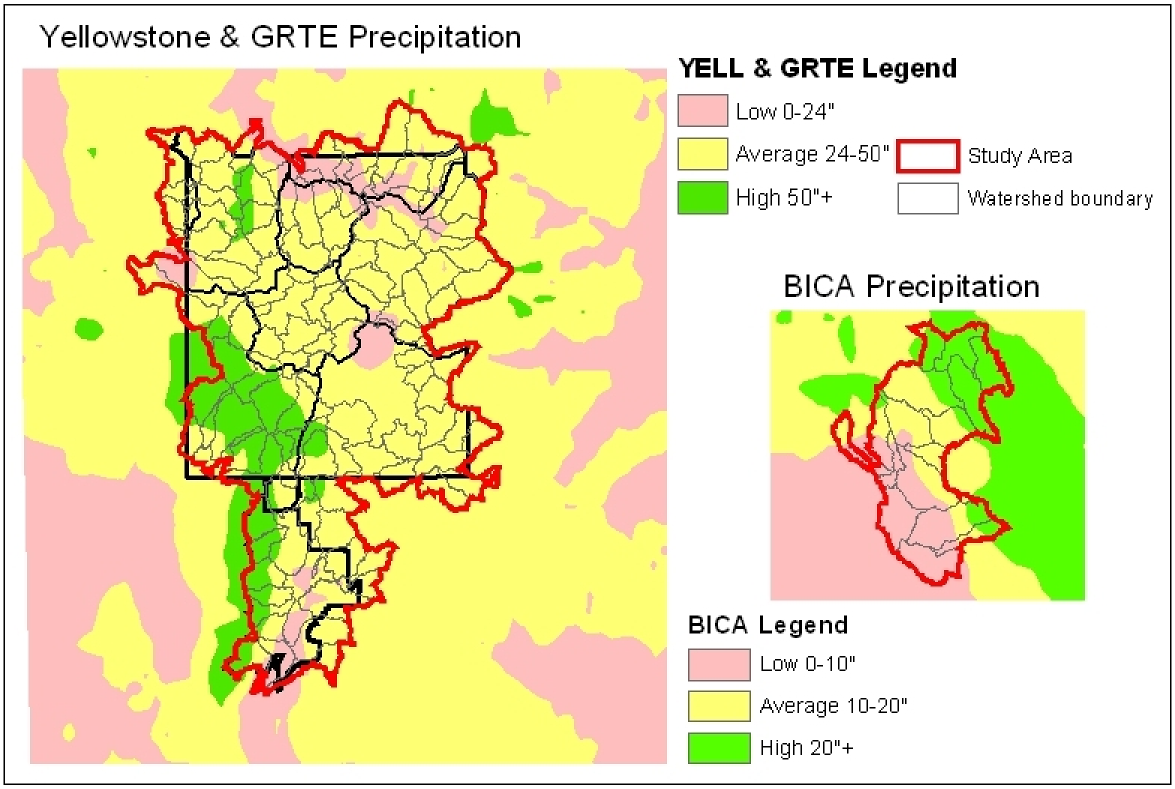
New Watershed Boundary layers created for this project (Project DVD: Data/HUCs)

B_HUC6 (B_HUC6GRID)	6th level HUC units for BICA that were developed from WQ_HUC6 (WQ_HUC6GRID)
G_HUC6 (G_HUC6GRID)	6th level HUC units for GRTE that were developed from WQ_HUC6 (WQ_HUC6GRID)
WQ_HUC6 (WQ_HUC6GRID)	6th level HUC units for GRYN that were developed from the source data from Montana, Idaho and Wyoming (gya_huc6.shp, ID_6TH_HUCS, and wy_hu12.shp) and clipped/merged together
Y_GT_HUC6 (Y_GT_HUC6GRID)	6th level HUC units for YELL and GRTE that were developed from WQ_HUC6 (WQ_HUC6GRID)
Y_HUC6 (Y_HUC6GRID)	6th level HUC units for YELL that were developed from WQ_HUC6 (WQ_HUC6GRID)



PRECIPITATION:

The amount of water added to a drainage will influence the composition of the water that leaves a drainage. We calculated the average precipitation in each study area then classified the areas into three relative categories: High (wetter than the average), Average (close to the average), and Low (drier than the average). Because GRTE and YELL have a similar climate we analyzed them together. The three YELL-GRTE categories are: High (>50 inches), Average (24 to 50 inches) and Low (0 to 24 inches). BICA has much lower rainfall so we created a different classification for those watersheds. For BICA the three categories are High (>20 inches), Average (10 to 20 inches), and Low (0 to 10 inches). This method seemed to do a good job in dividing up the study areas into dry, average, and wet zones. For the analysis we calculated the percent area of each category in each watershed.



Source data for Precipitation layers (Project DVD: Data/Precipitation/Original_Data)

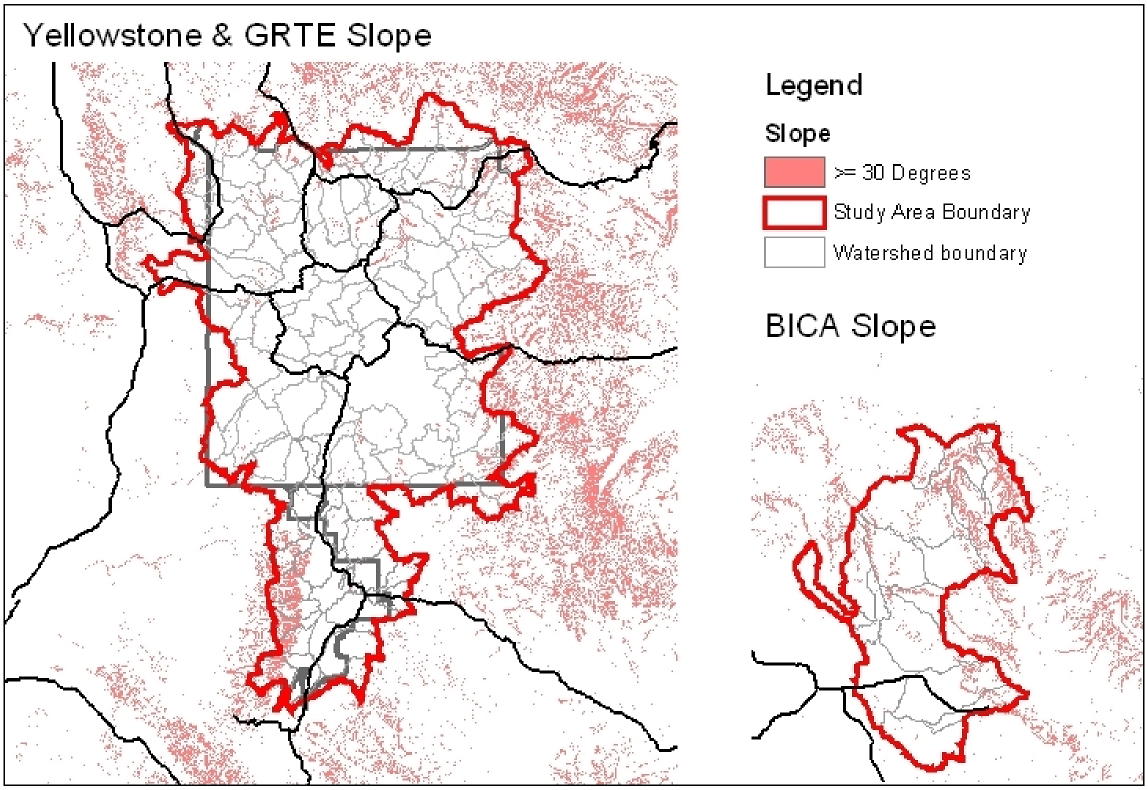
GYA_PRECIPALB (GYA_PRECIPUTM)	GYA precipitation data provided by the Interagency Spatial Analysis Center, Gallatin National Forest, Bozeman, Montana (and projected)

New Precipitation layers created for this project Project DVD: Data/Precipitation)

B_PRECIP	BICA precipitation data layer created from GYA_PRECIPUTM and reclassed to 3 = above average, 2 = average, and 1 = below average annual precipitation
Y_GT_PRECIP	YELL and GRTE precipitation data layer created from GYA_PRECIPUTM and reclassed to 3 = above average, 2 = average, and 1 = below average annual precipitation

SLOPE:

The steepness of the watershed affects how fast surface water moves through the watershed and how much time it has to soak into the soil. A study in Rocky Mountain National Park (Sueker et al, 2001) found that the percent of a watershed with slopes greater than 30 degrees had a big influence on the water chemistry. We used 30 meter digital elevation model data and calculated the area of the watershed with slopes greater than 30 degrees. In 38% of the GRTE watersheds, steep slopes (>30 degrees) make up more than 10% of the watersheds area. In YELL and BICA only 21% and 19% respectively of the watersheds have more than 10% of the watershed area with steep slopes (>30 degree slope).



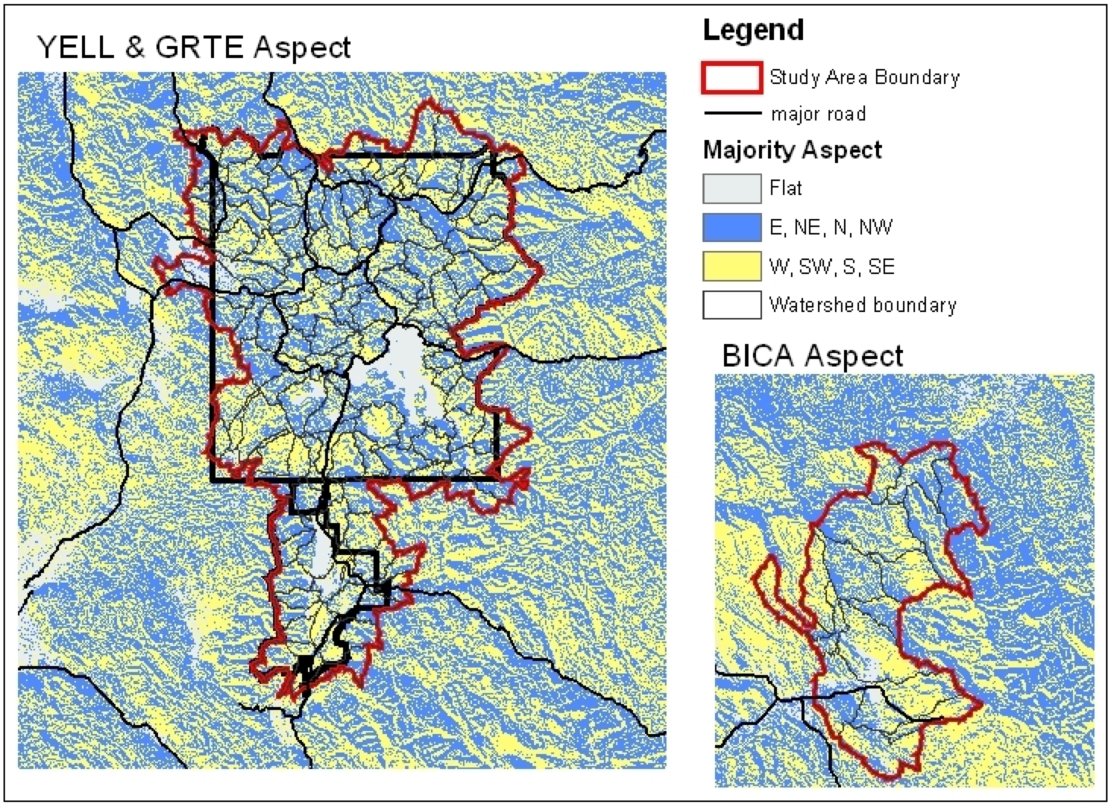
Source data for Slope layers (Project DVD: Data/Slope/Original_Data)

SLP30M_UTM83	- 30m Arc/Info GRID - created with the SLOPE command (degrees) in Arc/Info GRID using the elevation data (ELEV30M_UTM83) provided by the I&M group in Bozeman; given to I&M by Lisa Landenburger; Lisa downloaded from NED site
GA_SLOPE_30M	- 30m Arc/Info GRID - created with the SLOPE command (degrees) in Arc/Info GRID using the elevation data (GA_DEM_30M) housed in the Yellowstone Spatial Analysis Center

New Slope layers created for this project (Project DVD: Data/Slope)

B_SLOPE	BICA slope data created from SLP30M_UTM83 by clipping it to the BICA watershed classification project boundary; data were reclassed to 1 = greater than or equal to 30 degrees, and 0 = less than 30 degrees
Y_GT_SLOPE	YELL and GRTE slope data created from GA_SLOPE_30M by clipping it to the YELL/GRTE watershed classification project boundary; data were reclassed to 1 = greater than or equal to 30 degrees, and 0 = less than 30 degrees

ASPECT:
Aspect affects the amount and intensity of the solar radiation reaching the ground which in turn affects moisture levels in the watershed. We created a GIS coverage with nine categories (N, NE, NW, E, W, SE, SW, and S) from the 30 meter DEM data, then reclassified it into three categories. One was drier (S, SW, SE, W), one wetter (N, NE, NW, E) and one was flat (no aspect). For the analysis we calculated the percent area of each category in each watershed. Although aspect is important, especially in the drier areas, it tends to average out within a watershed and wasn't an important factor in differentiating one group of watersheds from another.



Source data for Aspect layers (Project DVD: Data/Aspect/Original_Data)

ASP30M_UTM83	- 30m Arc/Info GRID - created with the ASPECT command in Arc/Info GRID using the elevation data (ELEV30M_UTM83) provided by the I&M group in Bozeman; given to I&M by Lisa Landenburger; Lisa downloaded from NED site
GA_ASPECT_30M	- 30m Arc/Info GRID - created with the ASPECT command in Arc/Info GRID using the elevation data (GA_DEM_30M) housed in the Yellowstone Spatial Analysis Center

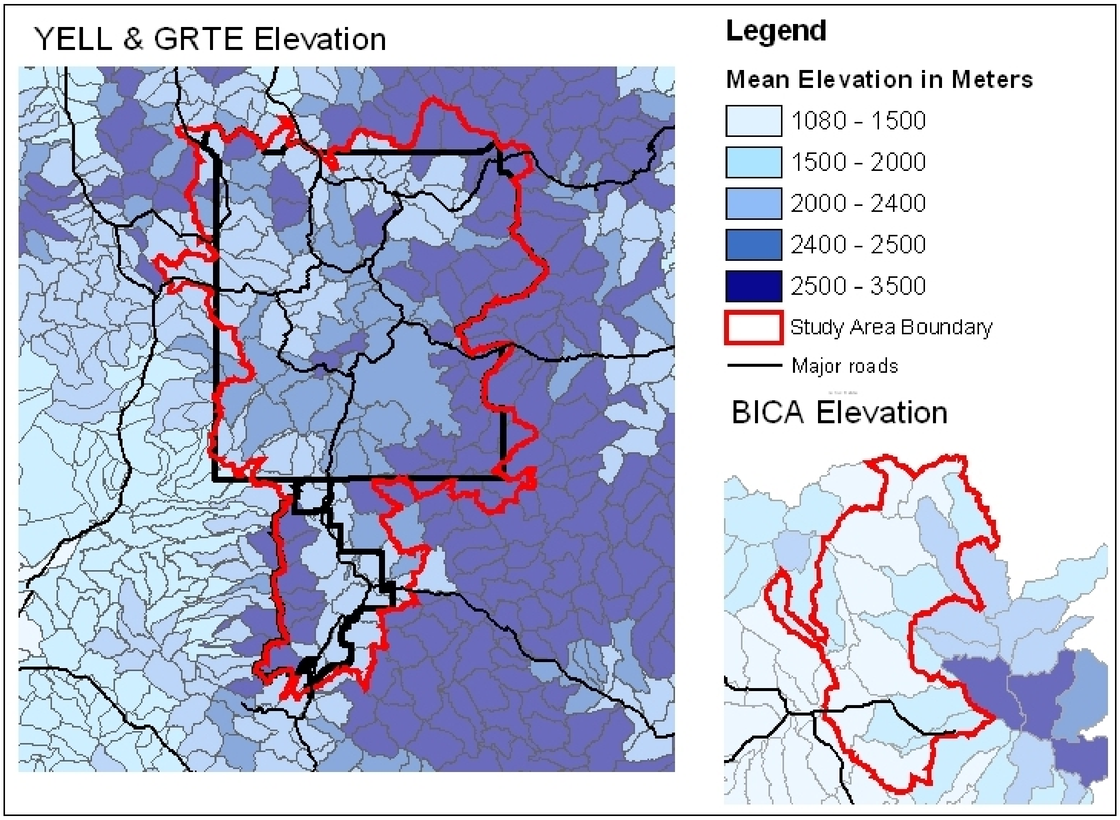
New Aspect layers created for this project (Project DVD: Data/Aspect)

B_ASPECT	BICA aspect data created from SLP30M_UTM83 by clipping it to the BICA watershed classification project boundary; data were reclassed to 0 = flat, 1 = N, NE, NW and E, and 2 = S, SE, SW, and W
Y_GT_ASPECT	YELL and GRTE aspect data created GA_SLOPE_30M by clipping it to the YELL/GRTE watershed classification project boundary; data were reclassed to 0 = flat, 1 = N, NE, NW and E, and 2 = S, SE, SW, and W

ELEVATION:

In the GYA, precipitation is often correlated with elevation and higher elevations retain snow longer. We used the 30 meter DEM data to calculate a mean elevation for each watershed. The range of mean elevations for YELL and GRTE watersheds were surprisingly similar and reinforced our idea of analyzing the two parks together. BICA watersheds have a much lower mean elevation.

Park	Lowest mean elevation	Highest mean elevation	Average mean elevation
BICA	1,197 m	1,837 m	1,456 m
GRTE	2,050 m	2,716 m	2,377 m
YELL	2,085 m	2,881 m	2,470 m



Source data for Elevation layers (Project DVD: Data/Elevation/Original_Data)

ELEV30M_UTM83	BICA 30 meter DEM data used to calculate slope and aspect; provided by the I&M group in Bozeman; given to I&M by Lisa Landenburger; Lisa downloaded from NED site
GA_DEM_30M	Core GYA (YELL and GRTE) 30 meter DEM used to calculate slope and aspect; housed in the Yellowstone Spatial Analysis Center

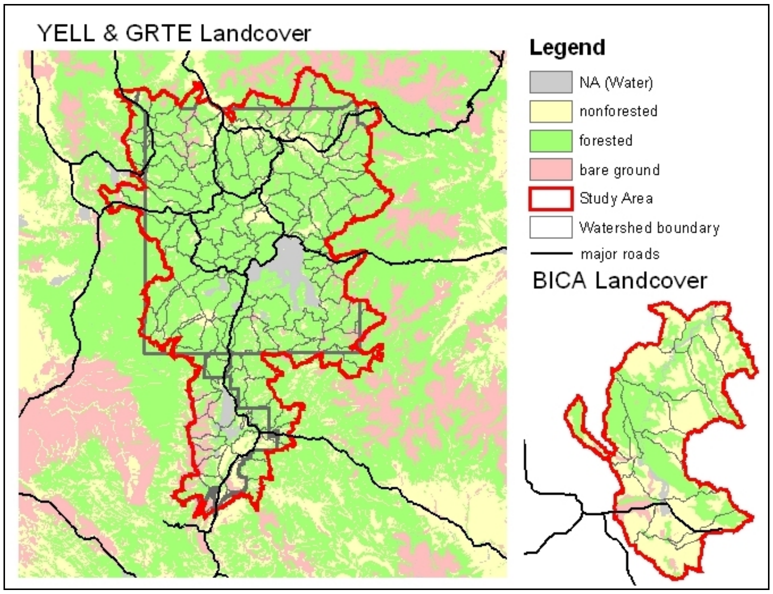
New Elevation Data layers created for this project (Project DVD: Data/Elevation)

WQ_HUC6 (WQ_HUC6GRID)	6th level HUC units for GRYN that were developed from the source data from Montana, Idaho and Wyoming (gya_huc6.shp, ID_6TH_HUCS, and wy_hu12.shp) and clipped/merged together

LANDCOVER:

Landcover affects runoff potential and infiltration rates. The more time the water spends in contact with rocks and soil, the more it will be influenced by the geochemistry of the substrate. Our source data is a land use/land cover coverage created by the United States Geologic Survey (USGS) at the 1:250,000 scale. We reclassified the original 31 classes into three new groups: Nonforested, Forested, Bare. In general these correspond to low runoff/high infiltration; medium runoff/medium infiltration; and high runoff/low infiltration. The table below shows how we reclassified the original classes into the new classes. It also shows the distribution of the three new classes within the three parks.

New classes	Original cover types	BICA	GRTE	YELL
Nonforested	Meadows, nonforested wetlands, and sandy areas (6 classes)	55%	25%	13%
Forested	Forested areas (4 classes)	41%	55%	80%
Bare	Urban areas, croplands, bare ground (21 classes)	4%	20%	7%



Data concerns:

- The original data were mapped at a scale where details were lost and small differences were lumped together. We did some accuracy assessment, but nothing vigorous. For example, the areas mapped as outcrop or talus on this data layer differ quite a bit from those mapped as outcrop and talus on a landform coverage for YELL that was mapped at a much finer scale. As always, the type of analysis appropriate for this data layer is limited by the mapping scale of the source data.

Source data for Landcover layers (Project DVD: Data/Landcover/Original_Data)

BICALULC	BICA landuse/landcover data developed from data downloaded from http://www.epa.gov/ngispgm3/sdata/EPAGIRAS/mgiras/
GA_LULC	GYA landuse/landcover data housed in the Yellowstone Spatial Analysis Center

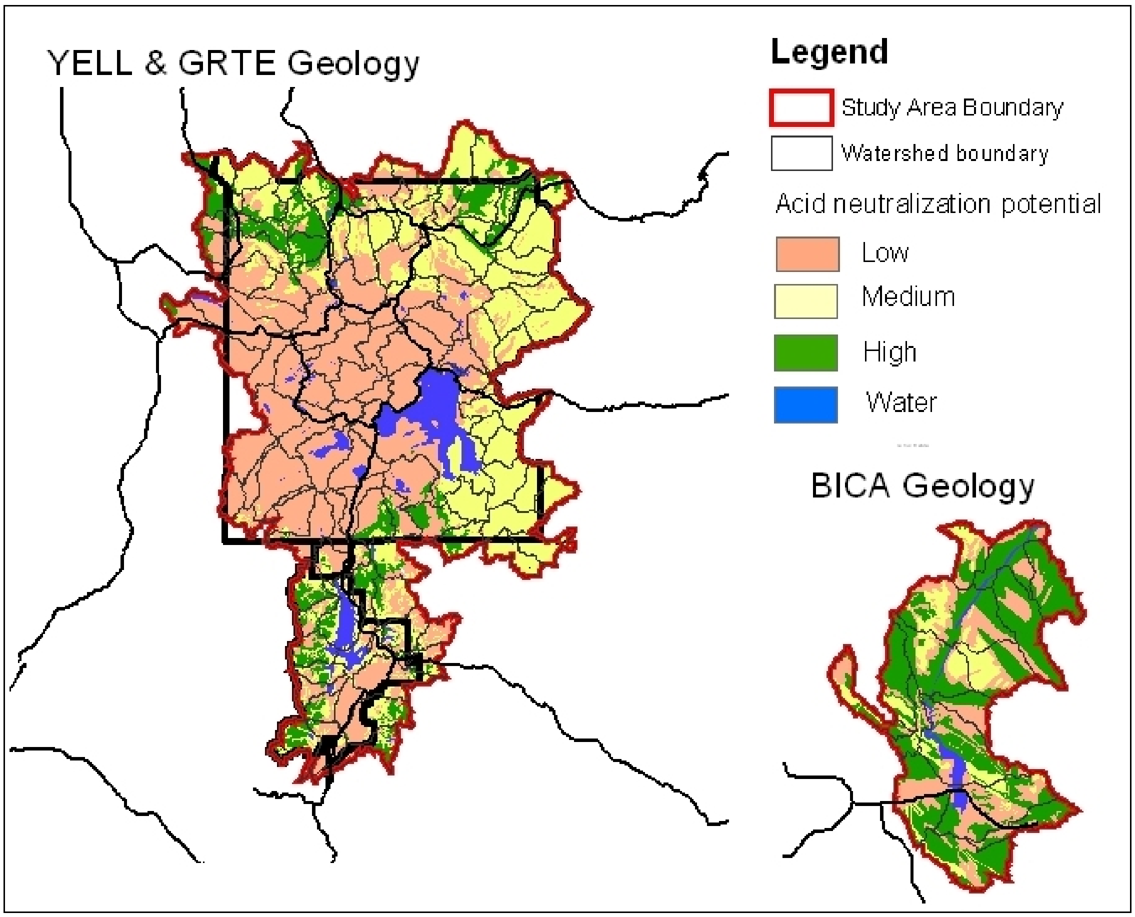
New Landcover layers created for this project (Project DVD: Data/Landcover)

Y_GT_B_LULC	YELL, GRTE and BICA landuse/landcover data created by merging 'BICALULC' and 'GA_LULC'; data were reclassed to 1 = nonforested, low runoff potential and high infiltration, 2 = forested, medium runoff potential and medium infiltration, and 3 = bare ground, high runoff potential and low infiltration

GEOLOGY:

Bed rock type and soil have a direct influence on surface water chemistry due to variations in types and proportions of released solutes as the minerals undergo chemical weathering. We wanted to account for the influence of geology and soils on the chemistry of the water leaving the watershed. We collected a lot of data for soils and geology from a variety of sources. Unfortunately the legends and scales were all very different and the metadata wasn't always available. Originally we decide to map the geology into six categories, but in the end we reclassified these six into just three final categories (Low, Medium, and High). In general the classes are based on weatherability, reactivity, and capacity to neutralize acids. The table and map below show the distribution of the three classes in the three parks.

Park	Low	Medium	High
BICA	30%	15%	55%
GRTE	50%	25%	25%
YELL	50%	40%	10%



Data concerns:

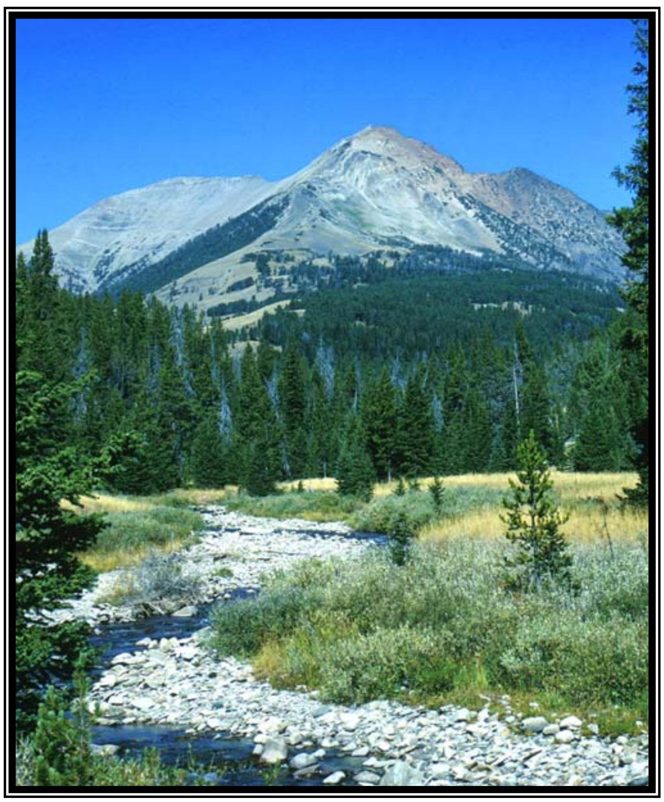
- The different source data were mapped at different scales for different purposes so edge-matching the attributes across boundaries was sometimes difficult.
- The reclassification of the geology attributes from the original data was done by different people in the different parks. We tried very hard to be consistent between people, but some differences in interpretation probably still remain.

Source data for Geology/Soils layers (Project DVD: Data/Geology/Original_Data)

mtgeology.shp	1:500,000-scale geology for the state of Montana; downloaded from http://nris.state.mt.us/gis/datalist.html (1:500,000 scale MBMG Geology)
wybedgeol.shp	1:500,000-scale geology for the state of Wyoming; downloaded from http://www.wygisc.uwyo.edu/clearinghouse/metadata/bedgeol.html
Y_GEOLOGY	1:125,000-scale geology of Yellowstone National Park and some surrounding areas; housed in Yellowstone's Spatial Analysis Center

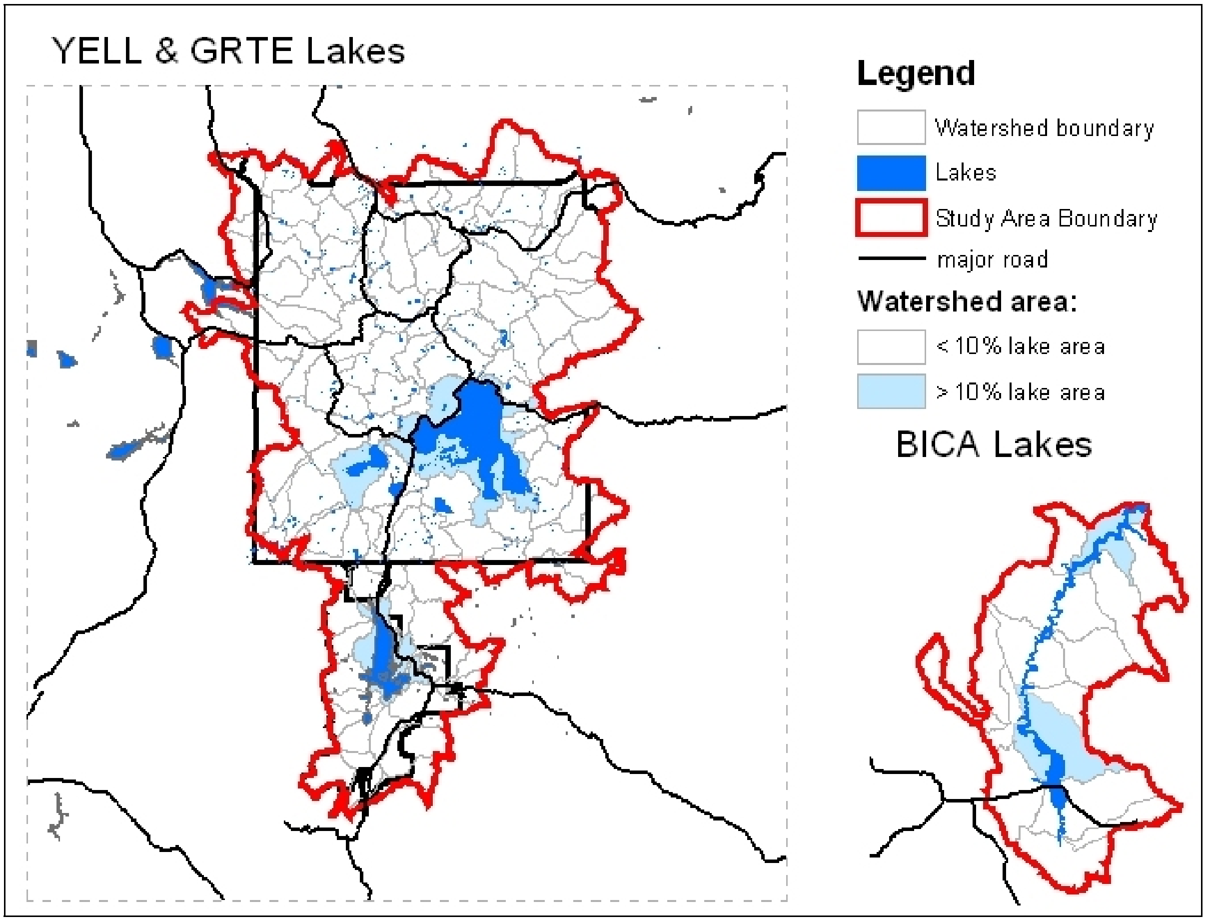
New Geology layers created for this project (Project DVD: Data/Geology)

B_GEOLGRID	BICA geology created from wybedgeol.shp and mtgeology.shp; reclassed into the following classes: 1 = low acid neutralizing ability (ANA), 2 = moderate ANA, 3 = high ANA, 4 = very high ANA, 5 = extremely high ANA, 6 = water
G_GEOLGRID	GRTE geology created from wybedgeol.shp and Y_GEOLOGY; reclassed into the following classes: 1 = low acid neutralizing ability (ANA), 2 = moderate ANA, 3 = high ANA, 4 = very high ANA, 5 = extremely high ANA, 6 = water
Y_GEOLGRID	YELL geology created from Y_GEOLOGY, wybedgeol.shp and mtgeology.shp; reclassed into the following classes: 1 = low acid neutralizing ability (ANA), 2 = moderate ANA, 3 = high ANA, 4 = very high ANA, 5 = extremely high ANA, 6 = water



LAKES:

Most of the assumptions about how various factors affect water quality are based on water/land interactions. In the few cases where lakes make up a significant percent of the total area of a watershed, these assumptions would be different. We used the “region.rch” subclass from the National Hydrologic Dataset (NHD) to calculate the percent area of lakes in each watershed. In the entire study area, lakes made up more than 10% of the total area of a watershed in only 6 watersheds (two in each park). So this is an important factor for a few watersheds, but overall in the analysis it didn’t have much influence.



Source data for Lake layer (Project DVD: Data/Surface_Water/Original_Data)

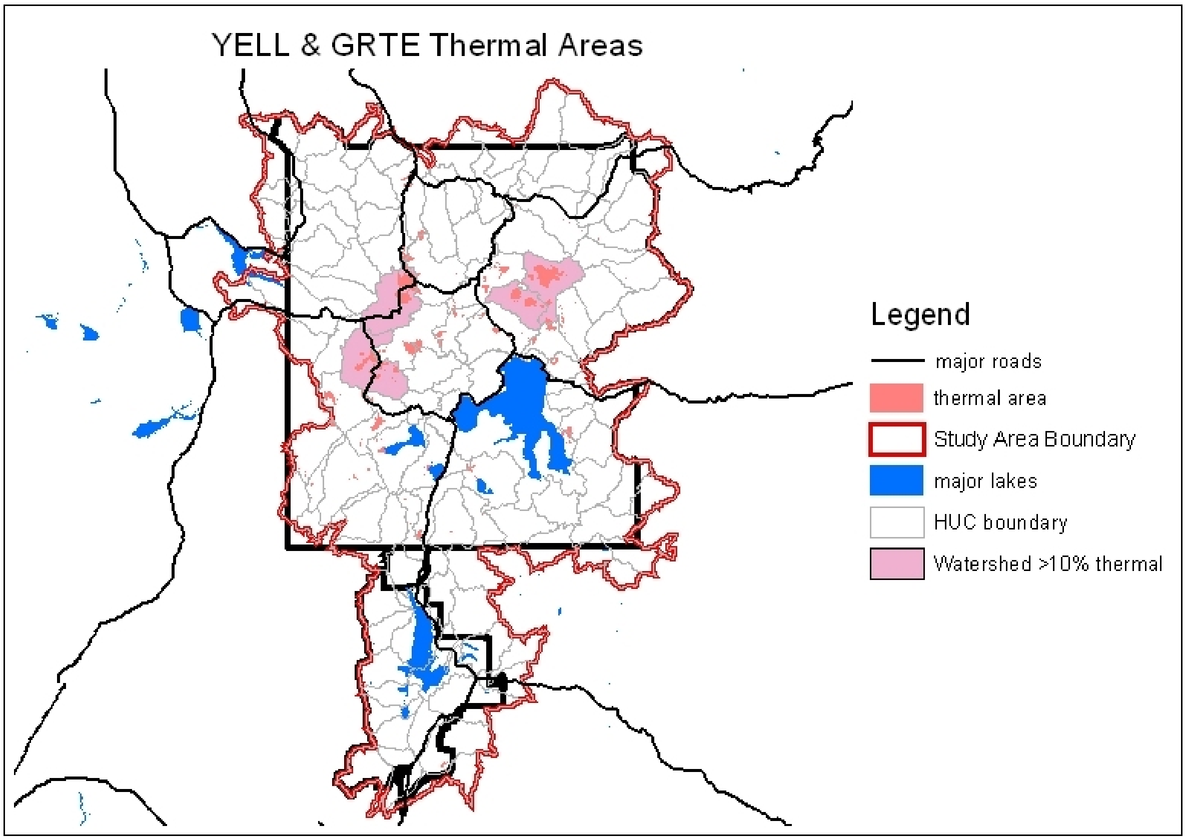
NHDWQPOLY (10020007, 10020008, 10070001, 10070002, 10070005, 10080010, 10080012, 10080014, 17040101, 17040102, 17040103, 17040202, 17040203)	NHD surface water data downloaded from the NHD website: http://nhd.usgs.gov/data.html; Data were downloaded by cataloguing unit (listed at left) and merged together using MAPJOIN in Arc/Info.

New Lake layer created for this project (Project DVD: Data/Surface_Water/)

Y_GT_B_WATER	YELL/GRTE/BICA water bodies created from NHDWQPOLY (clipped to the watershed classification project boundaries)

THERMAL AREAS:

Chemical additions from thermal areas will alter watershed chemistry differently than the normal (non-thermally influenced) interactions of water with bedrock and soil. For YELL, we created a GIS coverage of hydrothermally influenced soils to delineate areas that have been altered by interaction with hydrothermal activity. We created a new coverage to represent the thermal areas in Grand Teton. As far as we know, there is no significant thermal activity in BICA. Thermal areas were calculated as a percent of the total area of each watershed. In Yellowstone four watersheds have thermal areas that make up more than 10% of the total area of the watershed. These watersheds are highlighted in the map below. In the watershed containing Hot Springs Basin (100700010505) thermal areas make up 19% of the total area. This factor can have a significant influence on the chemistry in some Yellowstone watersheds, but overall it was a small contributor to differences between watersheds.



Source data for Thermal Area layers (Project DVD: Data/Thermal_Soils/Original_Data)

teton_thermal-areas.shp	GRTE thermal areas; The coordinates for this dataset were obtained from a text file of Hot Springs in the U. S. from the National Geophysical Data Center / WDC-A for Solid Earth Geophysics Boulder, Colorado USA web site. The polygon boundaries were digitized off the screen from DOQQs
Y_SOILS	YELL soil data; housed in the Yellowstone Spatial Analysis Center

New Thermal Area layers created for this project (Project DVD: Data/Thermal_Soils)

G_THERMAL (G_THERMGRID)	Thermal areas in GRTE; created from teton_thermal_areas.shp
Y_THERMAL (Y_THERMGRID)	Thermal areas in YELL, derived from Y_SOILS

LAKE BASINS:

Originally, we planned to apply the level 6 HUC watershed groupings to the lake basin GIS data that Nanus, et al (2003) were creating to assess high elevation lakes in GRTE and YELL. Unfortunately the level 6 HUCs are too large. The smallest watershed in the YELL-GRTE study area is 10,400 acres and many of the lake basins are smaller than 500 acres. Lake basin #213 in the map to the right is 110 acres in size. To apply our GIS classes to the lake basins, and group them like we grouped the level 6 HUC watersheds, we first had to create a lake basin GIS coverage. Using the data supplied by Leora Nanus, we created individual Arc/Info coverages for each lake basin (400 unique coverages). Lake name, SONYEW number, and headwater information were added to each coverage (if the information existed). Because many of the lake basins overlap each other, these multiple coverages were converted to region coverages then combined into one large coverage with a region subclass called "basins." The map to the right shows two overlapping lake basins near Shoshone Lake in YELL. We now have a lake basin GIS coverage that can be used to divide the lake basins into similar groups based on geology, precipitation, landcover, slope, aspect, etc.

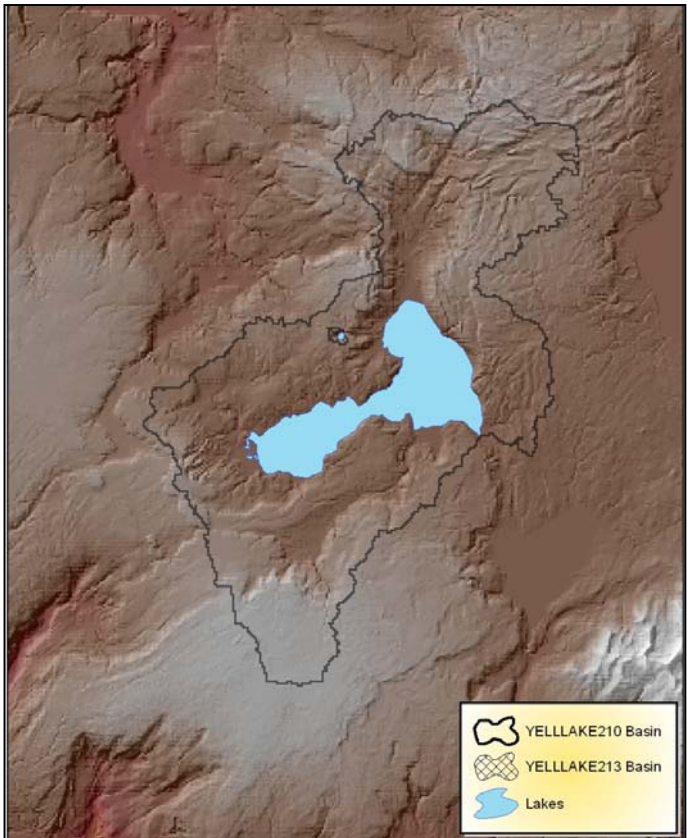


Figure 2. Lake basins associated with Shohone Lake and small, unnamed lake in Yellowstone National Park.

Source data for Lake Basin layers (Project DVD: Data/lake_basins/Original_Data)

LKENM_TETON	49 lakes in GRTE with names; all are greater than 1ha
LKE_NONAME	Lakes in GRTE with no names; all are greater than 1ha
WS_TETON_NAME	Watersheds associated with the lakes in LKENM_TETON
WS_TET_NONAME	Watersheds associated with the lakes in LKE_NONAME
YELL_LK_GT1HA	All lakes in YELL greater than 1ha
WS_YN_GT1HA	Watersheds in the north half of YELL associated with the lakes in YELL_LK_GT1HA
WS_YS_GT1HA	Watersheds in the south half of YELL associated with the lakes in YELL_LK_GT1HA

New Lake Basins layers created for this project (Project DVD: Data/lake_basins)

Y_GT_BASINS	An Arc/Info REGION coverage created by MAPJOINing all 400 individual Arc/Info coverages above; there are 400 regions under the subclass, "BASINS"

STRESSORS:

In our original proposal we planned to identify or create GIS data layers that would represent stressors to water quality. This included information about fire, grazing (domestic and wildlife), thermal areas, and human impacts (proximity to roads, trails, campsites, mining activity, oil & gas operations, developed areas, atmospheric deposition for S and N, etc.). We decided that thermal areas were similar to geology and belonged in the main analysis. Compiling data related to the other stressors turned out to be more than we could accomplish with the time and resources available. Instead, we will list what is known and continue to work on these layers in FY04.

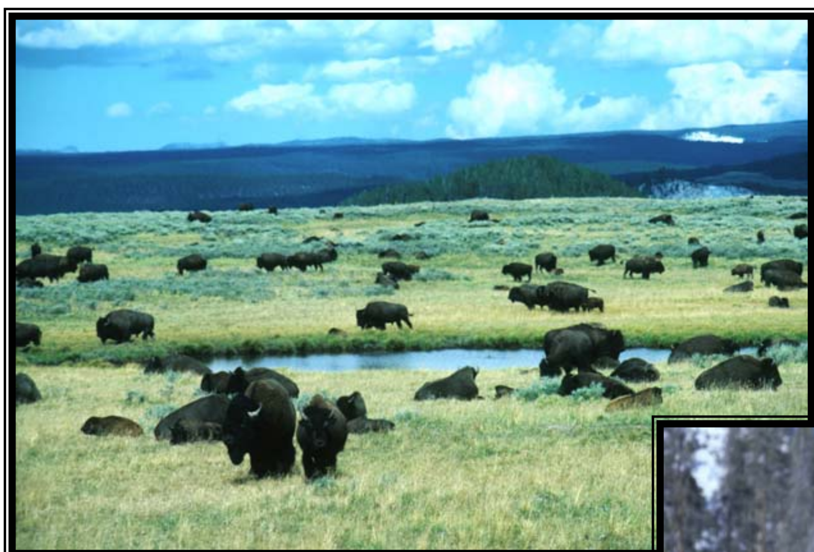
Fire impacts - We have fire history data sets for YELL and GRTE, but need data for BICA.

Grazing impacts - We have domestic grazing information for the areas surrounding YELL and GRTE that was last updated in 1998. This needs to be updated if possible. We have no information about domestic grazing in the BICA area. With input from wildlife biologists, it should be easy to delineate the general areas most heavily grazed by the major ungulates in YELL and GRTE. Resource management specialists in BICA might be able to provide that information as well.

Human use impacts - It is easy to make a buffer around roads, trails, developed areas, and campsites to represent an area of higher human impact. To make a more sophisticated layer that incorporates use statistics and emphasizes activities that have a greater affect on water quality will take more time.

Resource extraction impacts - We have completed a dataset that represents mining activity, oil & gas leasing, and geothermal drilling within and around all three parks. We need to intersect these data with the study area and the watershed boundaries to produce a map of potential impacts.

Atmospheric deposition impacts – We will rely on Leora Nanus (USGS) to provide this information.



STATISTICAL ANALYSIS - METHODS & RESULTS

METHODS

We created data tables for each park that listed the characteristics of each watershed based on the classes from each GIS data layer. We also created one data table that combined YELL and GRTE data so that we could analyze them together as a unit. The data tables are located on the project DVD under the Documentation folder. Most of the categories were characterized by calculating the percent of the area occupied by each GIS class in each watershed. The exceptions were mean elevation (listed in meters) and area (listed as acreage). Some of the statistics for watersheds 170401030102 and 170401010501 (both from GRTE) are shown below as examples. These watersheds are very different based on the statistics derived from the GIS classes and the cluster analysis did divide them into two different groups (*30102 in Group B and *10501 in Group C).

Lvl 6 HUC	Sfc water	Prec Low	Prec Avg	Prec High	Runoff Low	Runoff Med	Runoff High	Slope >30^{o}	Geol Low	Geol Med	Geol High	Elev (m)	Area (ac)
170401030102	1.9%	15%	25%	60%	18%	45%	37%	27%	16%	29%	55%	2,584	27,172
170401010501	0.5%	16%	84%	0%	54%	42%	4%	0.6%	63%	31%	6%	2,159	40,057

We used cluster analysis to classify the watersheds into groups with similar characteristics. Using an agglomerative, unweighted, average-linkage technique provides a balanced approach to create groups (Van Tongeren, 1995). Because cluster analysis does not provide information regarding the nature of differences between watershed clusters, principle components analysis (PCA; Ludwig and Reynolds, 1988) was used to determine which variables were most influential in grouping the HUCs. Knowing the actual basis for the difference between watershed groups will eventually help us interpret differences among them. This method was used successfully by Koel (2001) to group pools on the Mississippi River based on habitat.

RESULTS

We used the results of the cluster analysis and PCA on the four data tables (YELL, GRTE, BICA, and YELL-GRTE) to group the watersheds in each park. The nature of major watershed groups formed by cluster analysis and PCA was inferred from loadings of watershed characteristics (GIS coverage classes) for PCA axes 1 and 2. The PCA variable loadings table for GRTE is shown at right as an example. The highlighted classes are explaining most of the variation among watersheds, with yellow having the biggest influence on each axis. In general, the watershed groups for YELL, GRTE, and BICA were based primarily on different combinations of precipitation, geology, and land cover (*RUNOFF in the table).

PCA variable loadings - GRTE

	Axis 1	Axis 2	Axis 3	Axis 4
ACREAGE	0.011	0.010	-0.018	0.019
%WATER	0.001	0.070	-0.193	0.022
%THERMAL	0.001	0.000	-0.001	0.001
NASPECT	-0.148	0.099	0.086	-0.083
SASPECT	0.099	-0.062	0.112	0.031
ELEVA	-0.128	0.060	0.018	-0.101
GEOLLANA	0.214	-0.397	0.510	-0.494
GEOLMANA	0.027	0.197	-0.260	0.065
GEOLHANA	-0.243	0.132	-0.070	0.394
LRUNOFF	0.192	-0.332	-0.127	0.041
MRUNOFF	0.120	0.312	0.575	0.338
HRUNOFF	-0.313	-0.045	-0.268	-0.392
LPRECIP	0.170	-0.525	-0.200	0.351
MPRECIP	0.459	0.527	-0.119	-0.322
HPRECIP	-0.629	-0.002	0.319	-0.029
>30SLOPE	-0.247	0.007	-0.187	-0.283

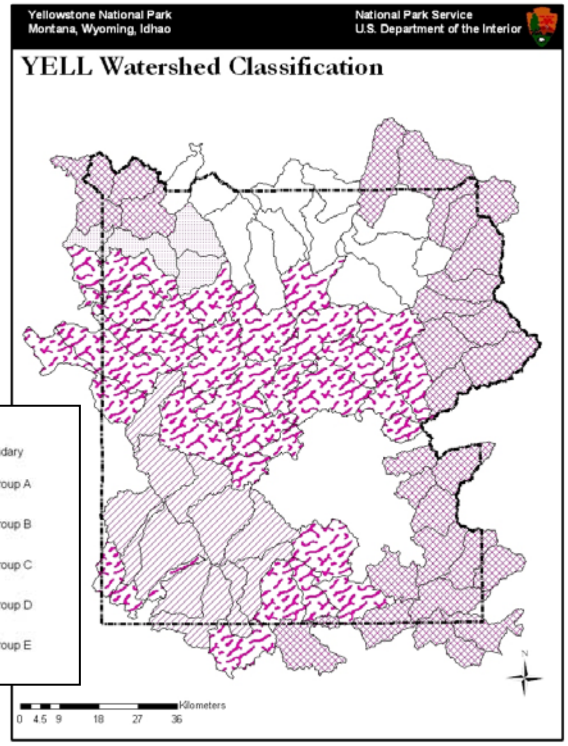
Eigenvalues

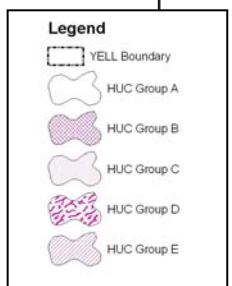
	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.259	0.155	0.077	0.043
Percentage	44.37	26.65	13.17	7.320
Cum. %	44.37	71.02	84.20	91.52

Files documenting the results of the analyses (Project DVD: Documentation folder)

*** pca loadings.txt** ** = YELL, GRTE, BICA, YELL&GRTE*	The Eigen values for each axes, PCA variable loadings for each GIS class, and PCA case scores for each watershed.
*** pca biplot.jpg** ** = YELL, GRTE, BICA, YELL&GRTE*	The PCA case scores plotted using Axis 1 and Axis 2. For YELL, GRTE, and BICA we have also added a polygon to delineate each classification group.
*** CLUSTER.wmf** ** = YELL, GRTE, BICA, YELL&GRTE*	Euclidean distance diagram showing the results of the agglomerative, unweighted, average-linkage technique.

Yellowstone – The 87 level 6 HUC watersheds in YELL were divided into five groups. Geology and precipitation, in that order, and to a lesser extent landcover (*RUNOFF), were the GIS classes that explained most of the variation among the YELL watershed groupings. In particular, low and medium geology classes, the medium and high precipitation classes, and the high geology class had the greatest influence. In general, groups (A, C, & E) below the horizontal axis (Axis 1) in Figure 3 receive higher than average precipitation and groups above the axis receive average precipitation. Groups (A & B) to the right of the vertical axis (Axis 2) will have lower weatherability, reactivity, and capacity to neutralize acids than the groups to the left of the axis.





PCA variable loadings - YELL

	Axis 1	Axis 2	Axis 3	Axis 4
ACREAGE	0.001	0.000	-0.003	0.005
%WATER	0.011	-0.009	-0.009	0.017
%THERMAL	0.023	0.033	-0.001	0.023
NASPECT	-0.041	-0.036	-0.152	0.033
SASPECT	0.009	0.039	0.156	-0.097
ELEVA	-0.046	0.038	0.081	-0.120
GEOLLANA	0.671	0.269	0.115	0.276
GEOLMANA	-0.624	-0.092	0.483	0.186
GEOLHANA	-0.062	-0.176	-0.588	-0.487
LRUNOFF	-0.027	-0.169	-0.211	0.274
MRUNOFF	0.106	0.197	0.252	-0.111
HRUNOFF	-0.090	-0.020	-0.031	-0.181
LPRECIP	-0.060	-0.238	-0.290	0.565
MPRECIP	-0.218	0.723	-0.099	-0.174
HPRECIP	0.278	-0.485	0.389	-0.391
>30SLOPE	-0.062	-0.021	-0.019	-0.065

Eigenvalues

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.325	0.106	0.058	0.046
Percentage	56.76	18.40	10.15	7.97
Cum. %	56.76	75.16	85.32	93.30

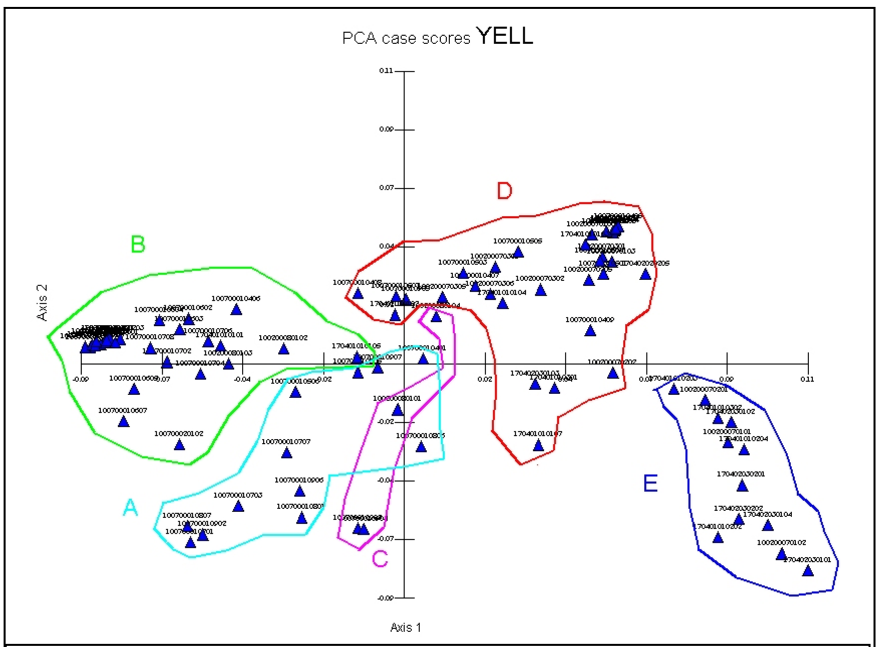
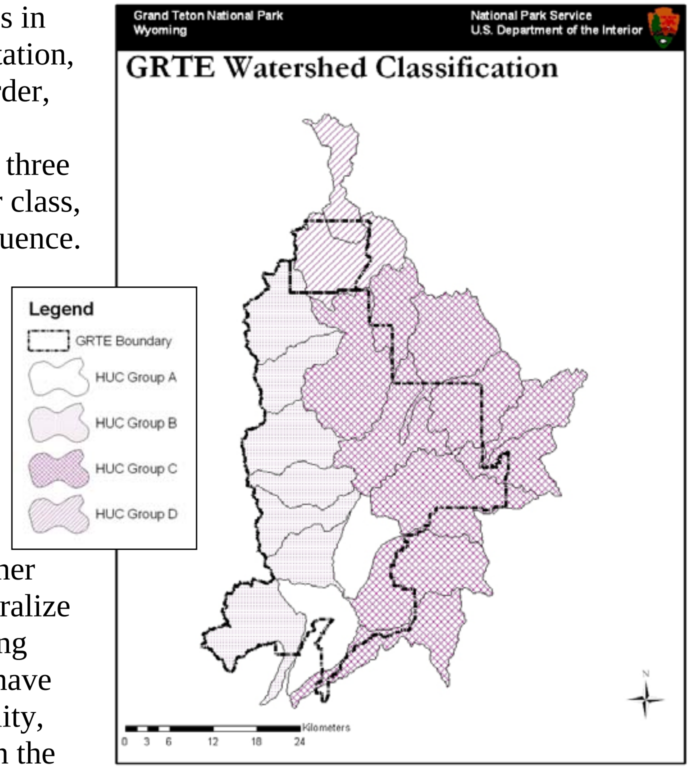


Figure 3. Two-dimensional scatterplot of Yellowstone watersheds on principle components axes 1 and 2.

Grand Teton – The 21 level 6 HUC watersheds in GRTE were divided into four groups. Precipitation, landcover (*RUNOFF) and geology, in that order, were the factors that explained most of the differences among the GRTE watersheds. All three classes of precipitation, the medium landcover class, and the low geology class had the greatest influence. GRTE was the only park in which steep slopes had much of an influence. In general, groups (C & D) to the right of the vertical axis (Axis 2) and above the horizontal axis (Axis 1) receive average precipitation while Group A recieves below average precipitation and Group B recieves above average precipitation. Group B also has steeper slopes, higher runoff potential and higher weatherability, reactivity, and capacity to neutralize acids than the other groups. In addition to being drier than the other groups, Group A tends to have lower runoff potential and a lower weatherability, reactivity, and capacity to neutralize acids than the other groups.



PCA variable loadings - GRTE

	Axis 1	Axis 2	Axis 3	Axis 4
ACREAGE	0.011	0.010	-0.018	0.019
%WATER	0.001	0.070	-0.193	0.022
%THERMAL	0.001	0.000	-0.001	0.001
NASPECT	-0.148	0.099	0.086	-0.083
SASPECT	0.099	-0.062	0.112	0.031
ELEVA	-0.128	0.060	0.018	-0.101
GEOLLANA	0.214	-0.397	0.510	-0.494
GEOLMANA	0.027	0.197	-0.260	0.065
GEOLHANA	-0.243	0.132	-0.070	0.394
LRUNOFF	0.192	-0.332	-0.127	0.041
MRUNOFF	0.120	0.312	0.575	0.338
HRUNOFF	-0.313	-0.045	-0.268	-0.392
LPRECIP	0.170	-0.525	-0.200	0.351
MPRECIP	0.459	0.527	-0.119	-0.322
HPRECIP	-0.629	-0.002	0.319	-0.029
>30SLOPE	-0.247	0.007	-0.187	-0.283

Eigenvalues

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.259	0.155	0.077	0.043
Percentage	44.37	26.65	13.17	7.320
Cum. %	44.37	71.02	84.20	91.52

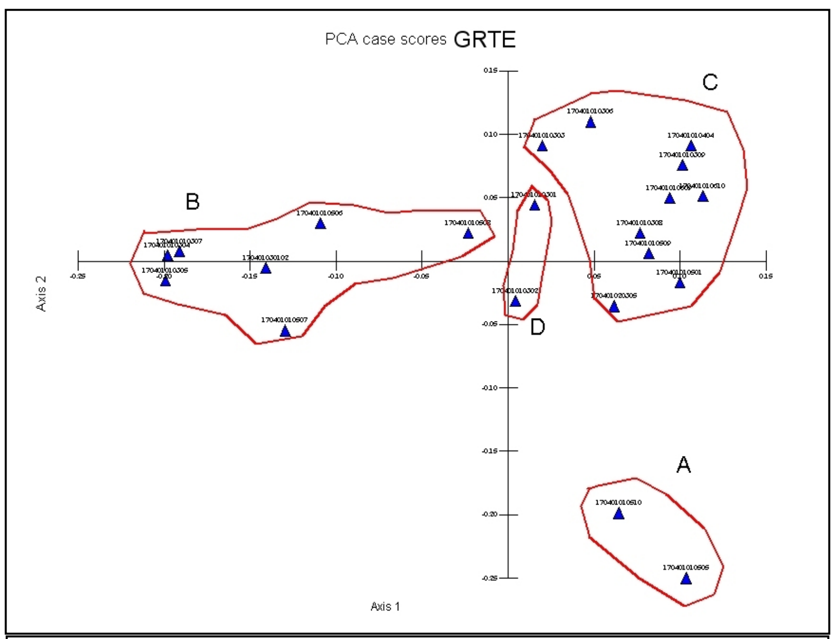
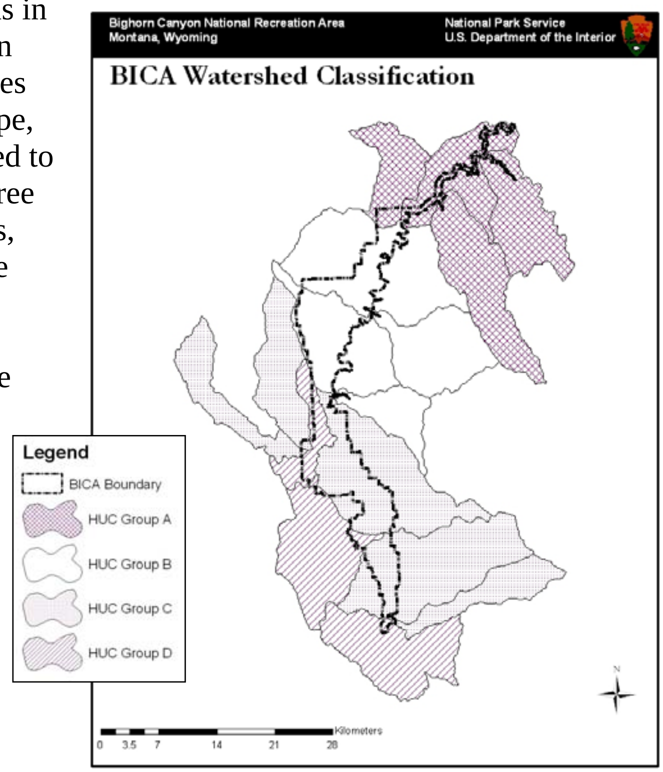


Figure 4. Two-dimensional scatterplot of Grand Teton watersheds on principle components axes 1 and 2.

Bighorn Canyon – The 16 level 6 HUC watersheds in BICA were divided into four groups. Precipitation dominates all other factors in explaining differences between BICA watersheds. To a lesser extent slope, aspect, and landcover (*RUNOFF) also contributed to the variation among the BICA watersheds. All three classes of precipitation, steep slopes, north aspects, forested and nonforested landcover classes had the greatest influence. Group A receives higher than average precipitation, Group B recieves average precipitation, while group D and parts of C receive lower than average precipitation. Group D is dominated by nonforested areas and Group A has steeper slopes and more north-facing aspects than the others.



PCA variable loadings - BICA

	Axis 1	Axis 2	Axis 3
ACREAGE	-0.005	-0.003	0.015
%WATER	0.012	0.003	-0.015
NASPECT	0.135	0.000	0.077
SASPECT	-0.109	-0.049	-0.093
ELEVA	0.062	-0.116	-0.083
GEOLLANA	-0.025	-0.029	0.246
GEOLMANA	-0.068	-0.115	0.147
GEOLHANA	0.098	0.147	-0.378
LRUNOFF	0.076	0.208	0.570
MRUNOFF	-0.028	-0.299	-0.594
HRUNOFF	-0.063	0.089	0.037
LPRECIP	-0.562	0.535	-0.143
MPRECIP	-0.192	-0.702	0.209
HPRECIP	0.754	0.167	-0.066
>30SLOPE	0.136	-0.004	-0.070

Eigenvalues

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.275	0.184	0.079
Percentage	44.57	29.74	12.73
Cum. %	44.57	74.31	87.04

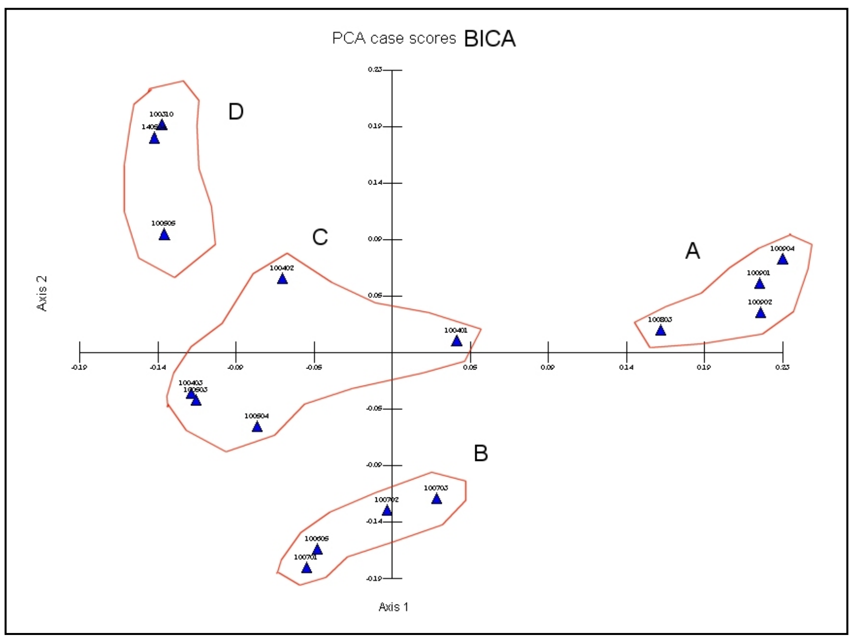
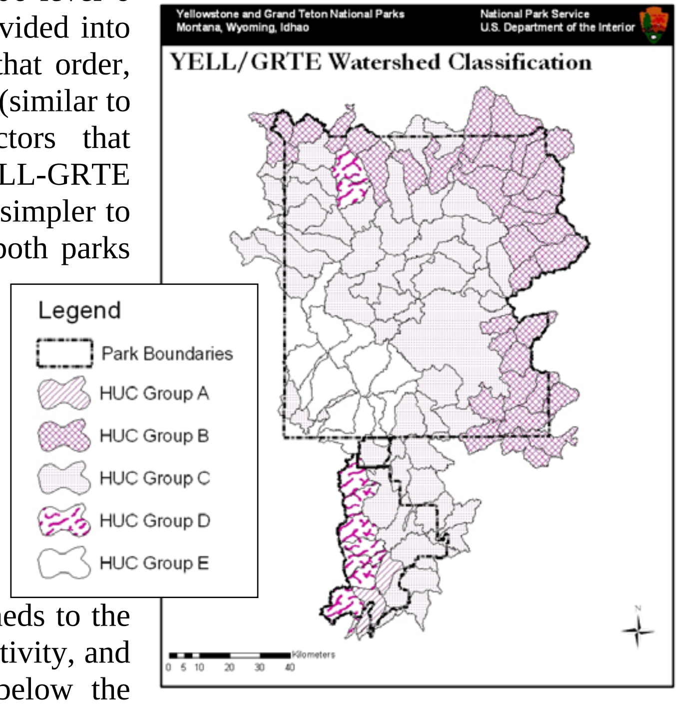


Figure 5. Two-dimensional scatterplot of Big Horn Canyon watersheds on principle components axes 1 and 2.

Yellowstone-Grand Teton combined – The 106 level 6 HUC watersheds in YELL & GRTE were divided into five groups. Geology and precipitation, in that order, and to a lesser extent landcover (*RUNOFF), (similar to the YELL analysis alone) were the factors that explained most of the variation among the YELL-GRTE combined watersheds. Although it would be simpler to design a water quality sampling design for both parks using one classification, some differences between GRTE watersheds were lost when we combined the analysis for both parks. The number of watersheds from YELL (86) compared to GRTE (20) forced geology to dominate over precipitation which changed the groupings in GRTE. In general, watersheds to the left of the vertical axis have moderate weatherability, reactivity, and capacity to neutralize acids while the watersheds to the right of the axis have low weatherability, reactivity, and capacity to neutralize acids. Watersheds below the horizontal axis receive higher than average precipitation and those above the axis receive average precipitation.



PCA variable loadings – YELL & GRTE	Axis 1	Axis 2	Axis 3	Axis 4
ACREAGE	0.001	0.001	-0.003	0.000
%WATER	0.005	-0.020	-0.012	0.016
%THERMAL	0.021	0.031	0.002	-0.004
NASPECT	-0.040	-0.034	0.055	0.086
SASPECT	0.011	0.048	0.025	-0.074
ELEVA	-0.045	-0.002	0.151	0.005
GEOLLANA	0.659	0.330	-0.129	-0.169
GEOLMANA	-0.616	-0.064	0.079	-0.521
GEOLHANA	-0.051	-0.256	0.060	0.678
LRUNOFF	-0.001	-0.124	-0.424	0.008
MRUNOFF	0.068	0.314	0.323	-0.198
HRUNOFF	-0.072	-0.172	0.113	0.174
LPRECIP	-0.027	-0.165	-0.617	-0.121
MPRECIP	-0.274	0.638	0.117	0.311
HPRECIP	0.301	-0.473	0.500	-0.190
>30SLOPE	-0.051	-0.124	0.079	0.099

Eigenvalues

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.277	0.140	0.072	0.052
Percentage	45.96	23.21	11.92	8.62
Cum. %	45.96	69.18	81.11	89.73

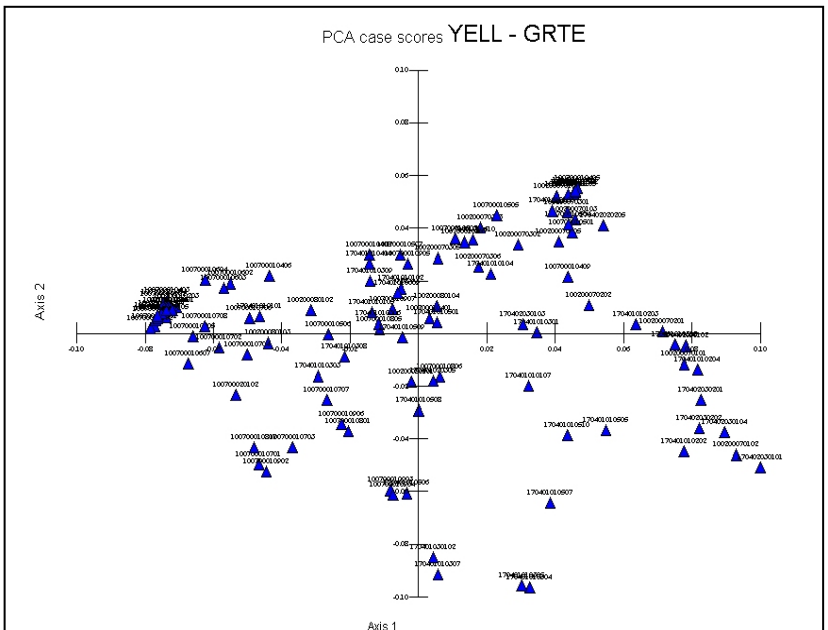


Figure 6. Two-dimensional scatterplot of the combined Yellowstone and Grand Teton watersheds on principle components axes 1 and 2.

COST SUMMARY

Category	Description	GYN	YELL
Salaries			
Shannon Savage	2pp	$	$5,200
Ann Rodman	1pp	$	$3,200
Jim Napoli	6pp	$ 5,500	$1,100
Adam Kiel	4pp	$ 3,300	$1,100
Peter Lindstrom	2pp	$ 2,200	$
Others (GIS)	1pp	$	$1,100
Others (Aquatic Resources)	0.5pp	$	$2,100
Travel	(GRTE to YELL)	$ 370	$
Supplies	printer, computer	$ 430	$
TOTAL		**$11,800**	**$13,800**

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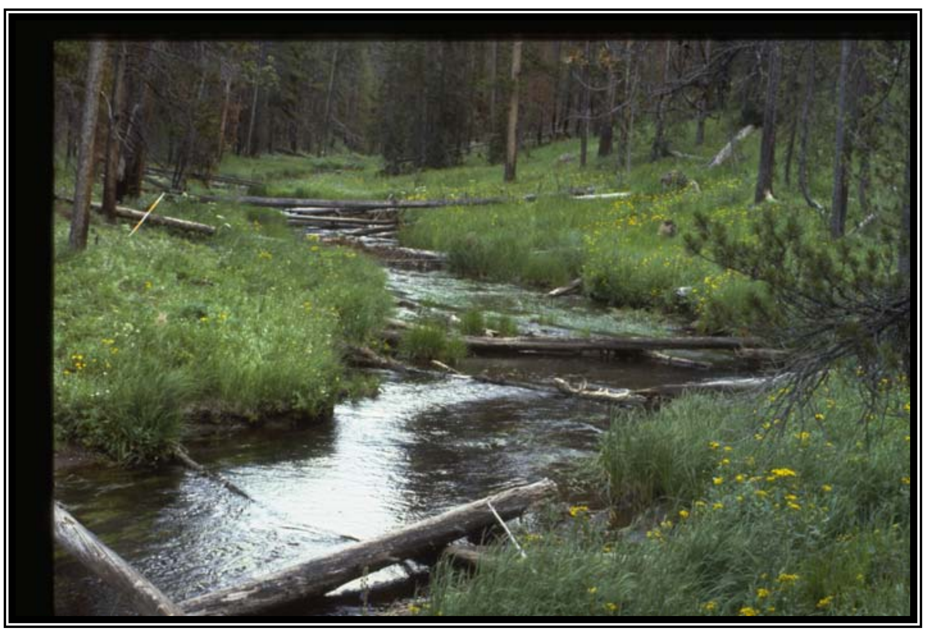

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The initial contact and network support for this project were provided by Network Program Manager Cathie Jean and GRTE Hydrologist Sue O'Ney. Peter Lindstrom , GRTE GIS Technician and Chad Jacobson, GRYN GIS Technician, provided data from GRTE and BICA respectively. Adam Kiel and Jim Napoli, YELL GIS Technicians, did most of the preliminary gathering of GYA-wide GIS data for the study areas. Adam also did the precipitation, landcover, and slope classifications for the study areas. Jim wrote much of the original proposal and literature review. Cheryl Jaworowski, YELL Pysical Science Technician, did the geology classification for BICA and GRTE. Jeff Arnold, YELL Aquatic Ecologist, gave valuable input on the original selection of watershed factors and stressors affecting water quality and also contributed the macroinvertebrate photograph on page 2. Kathy Mellander, Gateway NRA, created most of the maps included in the report. Additionally, Leora Nanus from the USGS, provided advice on watershed classifications and also provided her lake basin delineations for YELL and GRTE.